

LCA Methodology

Development of an Environmental Assessment Method for Consumer Electronics by Combining Top-Down and Bottom-Up Approaches

Pil-Ju Park^{1*}, Kun-Mo Lee² and Wolfgang Wimmer³¹ Research Center for Life Cycle Assessment, National Institute of Advanced Industrial Science and Technology (AIST), 16-1 Onogawa, Tsukuba, Ibaraki, 305-8569, Japan² School of Environmental, Civil and Transportation Engineering, Ajou University, San 5 Wonchun-Dong, Yeongtong-Gu Suwon, Korea 443-749³ Institute for Engineering Design, Vienna University of Technology, Getreidemarkt 9, 1060 Vienna, Austria

* Corresponding author (park-pj@aist.go.jp)

DOI: <http://dx.doi.org/10.1065/lca2005.05.205>**Abstract**

Goal, Scope and Background. Ecodesign requires environmental assessment methods, which are often time consuming and cost intensive. In this paper we proposed a method that combines top-down (e.g. LCA) and bottom-up (e.g. UNEP) approaches that allow one to generate ecodesign ideas by identifying what to improve, how much to improve, and how to improve within a short period of time. The proposed method incorporates an environmental assessment method for use in the ecodesign of consumer electronics that employs the top-down and bottom-up approaches simultaneously.

Method. The proposed method consists of five modules: A. life cycle thinking for a product, B. environmental benchmarking, C. checklist method, D. ecodesign strategies, and E. environmental design information. A key life cycle stage with significant environmental impact is identified in module A. When the identified key life cycle stage is not product manufacturing, environmental benchmarking is used; however, a checklist method is applied if product manufacturing is identified as the key life cycle stage. Ecodesign strategies for consumer electronics are obtained in module D. Environmental design information is produced by linking both the top-down and bottom-up information in module E.

Results and Discussion. The applicability of the proposed method was evaluated using mobile phones. First, the key life cycle stage of the mobile phone was identified as the raw material acquisition stage. Next, environmental benchmarking was carried out for 10 parameters belonging to the raw material acquisition stage. Environmental target specifications for the 10 parameters were set, ranging from 14% to 60%. Finally, environmental design information for the mobile phone was determined by linking the target specifications of the environmental benchmarking parameters and the corresponding ecodesign strategies.

The proposed method was also compared with the LCA and the UNEP/promising approaches, which are representative examples of the top-down approach and the bottom-up approach, respectively. Based on the results of this comparison, the proposed method was judged to be an advanced method in facilitating the generation of ecodesign ideas. Environmentally significant benchmarking parameters correspond to what to improve, target specifications on how much to improve, and ecodesign strategies on how to improve. It was found that the use of the proposed method minimizes the time and money expenditure by confining the identification of environmental weak points within the key life cycle stage.

Conclusion and Outlook. An environmental assessment method for consumer electronics in ecodesign was proposed and applied to mobile phones. The advantages of the proposed method are as follows: it is efficient and cost-effective, and it allows designers to generate ecodesign ideas more easily and effectively by simultaneously identifying the specific environmental weak points of a product and corresponding ecodesign strategies. The proposed method can be envisaged as a useful ecodesign approach when electronic companies identify the environmental aspects of their products and integrate them into product design and development process.

Keywords: Consumer electronics; ecodesign; ecodesign strategy; environmental assessment method; environmental benchmarking; environmental design information; life cycle assessment; mobile phone

Introduction

Concerted global efforts to achieve sustainable development have led to the development and implementation of various product-related environmental policies, regulations, and practices. For instance, there has been an overhaul of the EU chemicals policy (REACH (CEC 2001)), the implementation of electronic waste directives (WEEE (CEC 2003a), RoHS (CEC 2003b)), and a draft directive for the reduction of the environmental impacts of products through ecodesign (Energy-Using Product: EUP). The upcoming EUP directive (CEC 2003c) aims to improve the environmental performance of the energy-using products, for example consumer electronics, by encouraging manufacturers to engage in environmentally conscious design. According to this directive, manufacturers must quantify the environmental inputs and outputs of a product, consider life cycle analysis results in the product design, and offer environmental information to consumers. This indicates that manufacturers should approach the ecodesign of consumer electronics with the aim of creating products with improved environmental performance.

Ecodesign may be defined as the systematic integration of key environmental aspects of a product into the early stages of design and development. The ultimate aim of ecodesign is to improve a product's environmental performance. Basic

characteristics of a product, such as cost, functionality, performance, and reliability, must be considered simultaneously in the ecodesign process. Ecodesign concerns should be introduced at the earliest possible stage of product development, when the elements of design are most flexible. Approximately 80% of a product's design is fixed during the initial development stages, considerably limiting any subsequent changes that can be made. As product designers have great influence over every aspect of a design during the flexible early stages of development, they have an excellent opportunity to ensure that ecodesign principles are incorporated (Bhamra et al. 1999).

A generic model of product design and development in ISO/TR 14062 (ISO 2002) consists of six stages: planning, conceptual design, detailed design, testing/prototype, market launch, and product review. However, from an environmental perspective, it is more efficient to divide the process into different stages, considering that the purpose of ecodesign is to improve the environmental performance of a product by integrating environmental concerns into product design and development. With this in mind, we generalized existing ecodesign methods (Brezet et al. 1997, Gertsakis et al. 1997, Keoleian et al. 1993, Meinders 1997) into five stages: product planning, environmental assessment of a product, generation of ecodesign ideas, evaluation of ecodesign ideas, and application.

Of these stages, the environmental assessment of a product must be considered the most important. During this stage, key environmental aspects of a product are identified, and environmental information crucial to the generation of ecodesign ideas is revealed. We divided existing environmental assessment methods into top-down and bottom-up approaches, and analyzed each method. Next, we proposed an environmental assessment method for consumer electronics that combines the top-down and bottom-up approaches. Finally, we evaluated the applicability of the proposed method to the design of an actual product. The objective of this research was to propose an environmental assessment method for use in the ecodesign of consumer electronics that simultaneously employs both the top-down and bottom-up approaches.

1 Analysis of Existing Methods

As Fig. 1 illustrates, environmental assessment methods used in existing ecodesign methods can be broken down into top-down and bottom-up approaches. In the top-down approach (ISO 2002, Brezet et al. 1997), ecodesign strategies (or guidelines) are used in generating ecodesign ideas. In the bottom-up approach (Gertsakis et al. 1997, Keoleian et al. 1993, Meinders 1997), specific environmental weak points of a product (e.g. components, processes, or life cycle stages) are identified, and this information is used for the generation of ecodesign ideas. The principal advantage of the top-down approach is that it allows designers to generate creative ecodesign ideas using the ecodesign strategies (or guidelines). However, it is difficult to generate the best and most detailed ecodesign ideas with the top-down approach, as the improvement targets are often unclear. It is easier to gener-

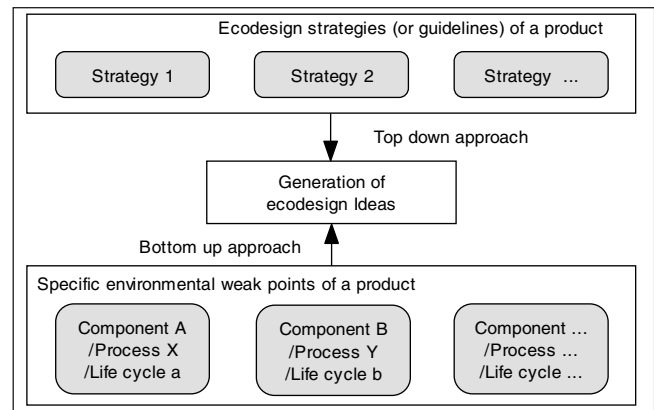


Fig. 1: Top-down and bottom-up approaches

ate ecodesign ideas for a product with the bottom-up approach, which entails the identification of the product's specific environmental weak points. The main disadvantage of the bottom-up approach is that bottom-up information is based on existing product; thus, it can be difficult to generate creative ecodesign ideas (Ha 2001).

There are many bottom-up approaches that one can use to identify a product's specific environmental weak points. Six typical methods – life cycle assessment (LCA) (ISO 1997), the MET (Material, Energy, and Toxicity) method (Kalisvaart et al. 1994), streamlined LCA (Christiansen 1997), the checklist method (Tischner et al. 2000), environmental benchmarking (Deckers et al. 2000), and quality function deployment for environment (QFDE) (JEMAI 2001) – are used commonly in the ecodesign. These methods were evaluated using three criteria; 1) cost and quickness, 2) design applicability, and 3) objectivity and reliability (Ha 2001). In product design and development, manufacturers seek a maximum reduction of time and cost. Environmental assessment results should be expressed in designer's languages, as this increases the applicability of the identified environmental information. Needless to say, objectivity and reliability of the environmental design information are crucial in any environmental assessment tools.

The results of our evaluation of the bottom-up environmental assessment methods are presented in Table 1. As shown in Table 1, the checklist method was deemed the most effective method in terms of cost and time savings. Environmental benchmarking and QFDE were superior to any other

Table 1: Evaluation of bottom-up environmental assessment methods

Tool \ Criterion	Cost and Quickness	Design applicability	Objectivity and Reliability
LCA	--	+/-	++
MET method	--	+	++
Streamlined LCA	+/-	+/-	+
Checklist method	++	+	-
Environmental benchmarking	+	++	+/-
QFDE	--	++	+

++ : very good, + : good, +/- : moderate, - : little, -- : very little

methods in design applicability. LCA and the MET method proved to be the best in objectivity and reliability. The results show that environmental benchmarking and checklist methods are the most effective in identifying the specific environmental weak points of a product.

The UNEP/promising approach (Brezet et al. 1997) is a typical top-down approach. In this approach, the major environmental weak points of a product emerge as one analyzes the product's environmental profile, internal ecodesign driver, and external ecodesign driver. The MET matrix and the ecodesign checklist are frequently used. The MET matrix is a simple qualitative method for assessing and prioritizing the environmental impacts of products during the entire life cycle. The ecodesign checklist provides supporting data for the qualitative environmental analysis by listing all the relevant questions that need to be asked when establishing the environmental bottlenecks. The weak points are then grouped according to the eight ecodesign strategies. Present environmental score as well as target score of each strategy is presented graphically in the ecodesign strategy wheel. Ecodesign strategies that have a greater difference between these two scores are used as the environmental design information. The UNEP/promising approach is quite strong in cost and quickness, and it is moderately strong in design applicability, objectivity, and reliability.

In the existing ecodesign methods, only one approach – either top-down or bottom-up – is used to identify the key environmental aspects of a product. With the top-down approach, it is often difficult to generate the best ecodesign ideas; however, when using the bottom-up approach, designers often face difficulty in generating creative ecodesign concepts. These problems can be solved by combining both the top-down and bottom-up approaches. When this is done, a product's specific environmental weak points are identified through the bottom-up approach, and then they are linked to corresponding ecodesign strategies. It is possible to generate ecodesign ideas more efficiently by simultaneously using the

environmental design information generated by the bottom-up (the product's specific environmental weak points) and top-down (corresponding ecodesign strategies) approaches.

2 The Proposed Environmental Assessment Method

Based on the results of our analysis of the existing methods, an environmental assessment method for consumer electronics was proposed (Fig. 2). The proposed method consists of five modules: a life cycle thinking for a product, environmental benchmarking, checklist method, ecodesign strategies, and environmental design information. Three different bottom-up approaches – LCA, environmental benchmarking, and checklist method – were used to identify the key environmental weak points of a product. Ecodesign strategies for consumer electronics were generated through the top-down approach.

In module A, a key life cycle stage (i.e. one that is associated with significant environmental impacts) is identified through the environmental assessment of a product. When the key life cycle stage is *not* product manufacturing, environmental benchmarking (module B) is used to identify the environmental weak points of the product. Alternatively, if product manufacturing is identified as the key life cycle stage, checklist method (module C) is applied, as it is difficult to benchmark the manufacturing stage of other companies. Ecodesign strategies for consumer electronics are obtained in module D. In module E, environmental design information is determined by linking the top-down and bottom-up information.

2.1 Module A – a life cycle thinking for a product

The aim of this module is to identify a key life cycle stage for the ecodesign of a particular product. While it is true that the environmental impacts associated with a product occur throughout the product life cycle, the environmental impacts of each life cycle stage are specific to the product's category. For example, in the case of durable goods (e.g.

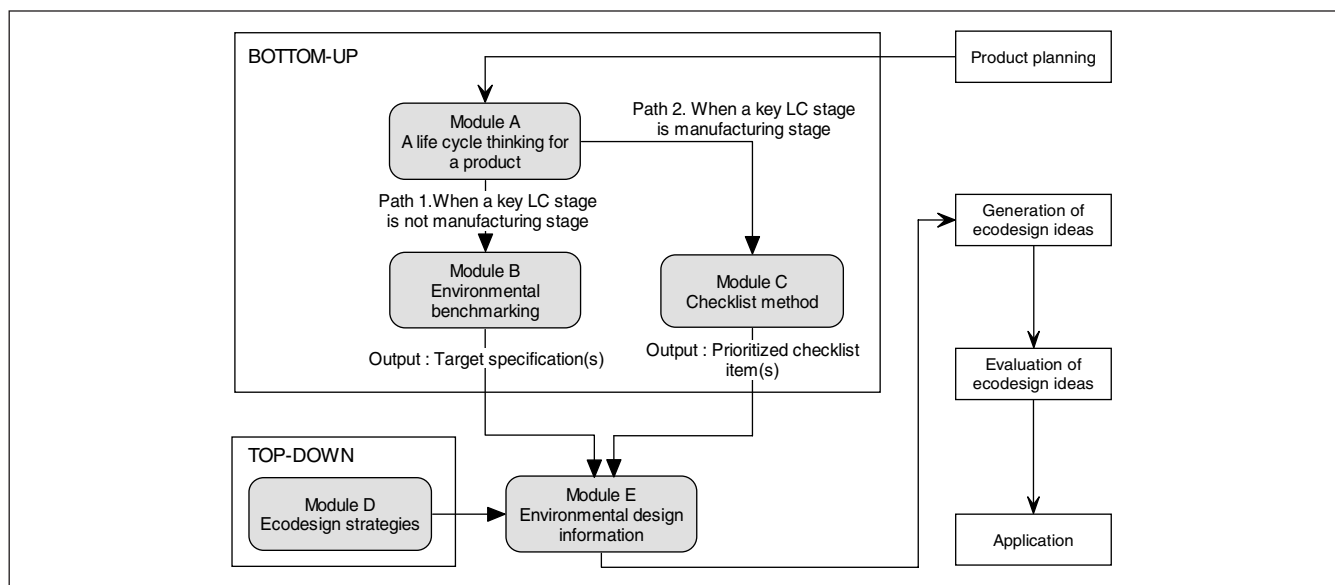


Fig. 2: Proposed environmental assessment method for consumer electronics

home appliances, automobiles), the environmental impacts from the use stage are much greater than those from the manufacturing and disposal stages. On the other hand, in the case of furniture, the environmental impacts of the raw material acquisition and manufacturing stages are much greater than those of the use stage. We maintain that it is more desirable to analyze a *key* life cycle stage than to analyze the entire life cycle. By analyzing only a key life cycle stage, one can not only reduce the time and money spent on the analysis, but also maximize the environmental improvements. Therefore, a key life cycle stage with significant environmental impacts is identified in this module. The product life cycle was divided into five stages: raw material acquisition, manufacturing, distribution, use, and disposal. A key life cycle stage is identified through the use of simple LCA-based methods, like a screening-level LCA (such as Ecoscan (TNO Industrial Technology 2004)) and an indicator method (such as Eco-indicator 99 (Goedkoop et al. 2000)). LCA results from the existing literatures may be used when the designer has no prior knowledge of the environmental assessment tools and methods. Note that the entire life cycle of a product has to be considered when applying simple LCA-based methods.

2.2 Module B – environmental benchmarking

When the key life cycle stage identified in module A is *not* the manufacturing stage - in other words, when it is the raw material acquisition, distribution, use, or disposal stage - the environmental benchmarking method is employed. Environmental benchmarking is an appropriate method for the identification of key environmental aspects of a product (see Table 1). However, existing environmental benchmarking methods have certain limitations, especially in terms of their ability to determine green focal areas and consider the entire life cycle of a product systematically (Deckers et al. 2000, Yim et al. 2002). In this module, we proposed environmental benchmarking parameters for each of the four life cycle stages, as well as a method for determining the target specifications of these parameters.

Three steps were followed to determine the required environmental benchmarking parameters. First, index items were evaluated for the environmental aspects of a product, based on advanced companies' environmental and sustainability reports. Second, temporal environmental benchmarking parameters were generated in an expert panel meeting. The expert panel was composed of seven to ten individuals, each of whom possesses at least six months of experience in ecodesign. Third, the environmental benchmarking parameters were modified after they are applied to a real product. Following these steps, we determined a total of 31 environmental benchmarking parameters, as shown in Table 2. Depending on the attribute of each parameter, either positive or negative sign is given to each parameter, and denoted as '+' or '-'. A negative parameter indicates that the smaller the measured value is, the better the environmental performance is. Parameters such as product weight, material quantity, number of components, and energy consumption are examples of the negative parameters. A positive parameter indicates that the greater the measured value is, the better the environmental performance is.

Three criteria are applied when determining the target specifications of the benchmarking parameters: the legal requirements, competitors' benchmarking results, and company's own environmental goals. The first step is to verify that the benchmarking results for a reference product meet the legal requirements. If they do not, the environmental target specifications are created that do conform to the legal requirements. If the benchmarking results for the reference product do meet the legal requirements, they are compared with those of competitors' products. If the benchmarking results of the reference product are inferior to those of competitors' products, the latter become the environmental target specifications. On the other hand, if the benchmarking results of the reference product are superior, the company's own environmental goals become the target specifications of the benchmarking parameters. The final output of this module is the target specifications for environmentally significant benchmarking parameters.

Table 2: Proposed environmental benchmarking parameters for consumer electronics

Life cycle stage	Environmental benchmarking parameter	Attribute	Life cycle stage	Environmental benchmarking parameter	Attribute
Raw material acquisition	1. Hazardous material content	-	Use	17. Charger energy efficiency	-
	2. Marking of hazardous components	+		18. Stand-by mode energy consumption	-
	3. Surface area of PCB	-		19. Operational mode energy consumption	-
	4. Number of components on PCB	-		20. Amount of consumable needed	+
	5. Surface area of LCD	-		21. Recycled material content	+
	6. Ratio of weight/length cable (or wiring)	-	Disposal	22. Recyclable material content	+
	7. Weight of packaging material	-		23. Reusable part	+
	8. Weight of a product	-		24. Number of joints	-
	9. Number and weight of accessory parts	-		25. Number of tools for disassembly	-
	10. Number of kinds of material	-		26. Disassembly time	-
	11. Number of parts	-		27. Number of types of joints	-
Distribution	12. Weight and number of users manual	-		28. Number of parts	-
	13. Ratio of packaging weight/product weight	-		29. Marking of materials	+
	14. Volume of packaging box	-		30. Number of kinds (variety) of material	-
	15. Weight of total product including packaging	-		31. Warranty period	+
	16. Volume of total product including packaging	-			

-: Negative parameter, +: Positive parameter

2.3 Module C – checklist method

As noted previously, environmental benchmarking cannot be employed when the key life cycle stage identified in module A is the manufacturing stage. Although manufacturing-related data on other companies can be acquired through the environmental and sustainability reports, such information is not adequate for use in identifying the key environmental weak points of the manufacturing stage for the purposes of ecodesign. Therefore, the checklist method is used. This method represents an appropriate way to identify the key environmental aspects of a product (see Table 1). The determination of checklist items and the selection of evaluation methods are the most important steps in this module. In the present study, checklist items were proposed for four categories: ancillary material, energy, waste, and environmental emissions. Checklist items related to the product itself were excluded, as these were already considered in the environmental benchmarking module. The first step in setting up checklist items for the manufacturing stage was to review the existing checklist items (Brezet et al. 1997, Clark et al. 1999, Wimmer et al. 2001). Next, appropriate checklist items for consumer electronics were selected by the expert panel described above. As shown in Table 3, a total of 16 checklist items were obtained. The checklist items can be evaluated using the three evaluation criteria, as delineated by the ecodesign PILOT (Product Investigation, Learning, and Optimization Tool for Sustainable Product Development) method (Wimmer et al. 2001): 1) the relative impor-

tance of the individual checklists for a given product, 2) assessment performance, and 3) implementation risk. The output of this module is a set of prioritized checklist items.

2.4 Module D – ecodesign strategies for consumer electronics

Ecodesign strategies are environmental improvement strategies that are tailored to a specific product's context and environmental impacts. Ecodesign strategies are designed to minimize a product's environmental impacts while enhancing its design characteristics. They must be defined differently for various product categories, as the environmental characteristics of product categories are unique. In the present study, the aim of this module was to develop appropriate ecodesign strategies for consumer electronics. Ecodesign strategies for consumer electronics were predetermined based on the results of an analysis of the existing ecodesign strategies (Brezet et al. 1997, Keoleian et al. 1993, Thomption 1999, Tischner et al. 2000, Wimmer et al. 2001). When determining ecodesign strategies for consumer electronics, we used two kinds of categories for ease of generating ecodesign ideas in module E. The first category of attributes included product, material, and energy, and the second category included use, disposal, life span, and package. Proposed ecodesign strategies were reviewed and modified by the expert panel. A total of 25 ecodesign strategies were developed, as shown in Table 4. Using the two kinds of attributes presented in Table 4, users can easily choose proper ecodesign strategies for their products. For example, by referring to

Table 3: Selected checklist items for the manufacturing stage

Category	Checklist item	Category	Checklist item
Ancillary material	Preferably use ancillary materials from renewable raw materials	Waste	Use low emission production technologies
	Recycle ancillary materials whenever possible		Avoid environmentally hazardous production technologies
	Use environmentally acceptable ancillary materials		Avoid waste in the production process
	Avoid hazardous ancillary materials		Close material cycles in the production process
Energy	Use energy efficient production technologies		Recycle/reuse waste for new materials
	Reduce energy consumption by optimum process design		Dispose of unavoidable waste in an environmentally acceptable manner
	Preferably use renewable energy resources		Waste sorting/separation whenever possible
	Minimize overall energy consumption of production site	Emissions	Avoid environmental emissions in the production process

Table 4: Proposed ecodesign strategies for consumer electronics

Category	Ecodesign strategy		Category	Ecodesign strategy	
Product related	Use	a. Indication of resource/energy consumption along use stage	Material related	Use	m. Avoidance/reduction of toxic materials
		b. Materials labeling including instructions for disposal			n. Minimization of process materials in use stage
	Disposal	c. Easy disassembly			o. Reduction of material input
		d. Inclusion of disposal instructions for users			p. Reduction of the number of materials/parts
	Life span	e. Easy maintenance and repair			q. Reuse of refurbished parts and components
		f. Easy upgradability			r. Use of lower energy content materials
		g. Environmentally friendly surface design			s. Use of recyclable materials
		h. Function integration			t. Use of recycled materials
		i. Standardization of components			u. Use of renewable materials
Energy related	Use	j. Minimization of energy consumption in use stage	Material related	Disposal	v. Minimization of waste/ environmental emissions
		k. Minimization of energy consumption in production stage			w. Waste recycling/reuse
		l. Use of renewable energy resources		Package	x. Optimization of the weight /volume of packaging material
					y. Use of reusable packaging material

Table 4, one can easily recognize two strategies that relate to both product and disposal: *easy disassembly* and *inclusion of disposal instructions for user*.

2.5 Module E – environmental design information

Designers often do not have sufficient information about the environmental characteristics of a product. In addition, they often lack insight into how to improve the environmental aspects of a product. In order to ensure that designers can easily generate environmental improvement ideas, the specific environmental aspects of a product and corresponding ecodesign strategies should be furnished to them simultaneously. With this goal in mind, we link environmental benchmarking parameters and checklist items to corresponding ecodesign strategies in this module. In our study, relationships between benchmarking parameters or checklist items and ecodesign strategies were determined using the Delphi method. The Delphi method (Linstone et al. 2002) is a group decision process about the likelihood that certain events will occur. The Delphi method makes use of a panel of experts, who are selected based on the areas of expertise required. The guiding assumption is that well-informed individuals, calling on their insights and experience, offer better predictive insight than do theoretical approaches or extrapolations of trends. In the present study, the procedures for determining the relationships between the top-down and bottom-up approaches were as follows:

- The determined environmental benchmarking parameters, checklist items, and ecodesign strategies were distributed to each member of the expert panel before their meeting.

- During the meeting, relationships between ecodesign strategies and environmental benchmarking parameters or checklist items were identified.
- The results of step 2 were distributed to each member of the expert panel, and the relationships were reviewed.
- Steps 2 and 3 were repeated until consensus was reached.
- If consensus among the members of the panel was not reached, majority rule was applied.

Table 5 (see following page) shows the relationships between benchmarking parameters and ecodesign strategies, and Table 6 presents the relationships between checklist items and ecodesign strategies. In Table 5 and Table 6, each benchmarking parameter or checklist item is related to between one and six ecodesign strategies. This indicates that there can be more than one strategy applicable to improving the environmental aspects of a product represented by the significant environmental parameters.

Two different paths are taken in this module, as two different methods are used in identifying the specific environmental aspects of a product. When the key life cycle stage identified in module A is not manufacturing, target specifications of the environmentally significant parameters and corresponding ecodesign strategies for these parameters are used in generating the ecodesign ideas. When the key life cycle stage is manufacturing, high-priority checklist items and corresponding ecodesign strategies are used.

Table 6: The relationship between checklist items and ecodesign strategies

Category	Checklist item	Ecodesign strategy
Ancillary material	Preferably use ancillary material from renewable raw materials	o. Reduction of material input r. Use of lower energy content materials
	Recycle ancillary materials whenever possible	w. Waste recycling/reuse
	Use environmentally acceptable ancillary materials	m. Avoidance/reduction of toxic materials r. Use of lower energy content materials
	Avoid hazardous ancillary materials	m. Avoidance/reduction of toxic materials
Energy	Use energy efficient production technologies	k. Minimization of energy consumption in production stage l. Use of renewable energy resources
	Reduce energy consumption by optimum process design	k. Minimization of energy consumption in production stage l. Use of renewable energy resources
	Preferably use renewable energy resources	l. Use of renewable energy resources
	Minimize overall energy consumption of production site	k. Minimization of energy consumption in production stage l. Use of renewable energy resources
Waste	Use low emission production technologies	v. Minimization of waste/environmental emissions
	Avoid environmentally hazardous production technologies	k. Minimization of energy consumption in production stage
	Avoid waste in the production process	v. Minimization of waste/environmental emissions
	Close material cycles in the production process	w. Waste recycling/reuse
	Recycle/reuse waste for new materials	w. Waste recycling/reuse
	Dispose of unavoidable waste in an environmentally acceptable manner	w. Waste recycling/reuse
	Waste sorting/separation whenever possible	w. Waste recycling/reuse
Emission	Avoid environmental emissions in the production process	v. Minimization of waste/environmental emissions

Table 5: The relationship between benchmarking parameters and ecodesign strategies

Life cycle	Benchmarking parameter	Ecodesign strategy	Life cycle	Benchmarking parameter	Ecodesign strategy
Raw material acquisition	1. Hazardous material contents	m. Avoidance/reduction of toxic materials	Use	17. Amount of consumable needed	a. Indication of resource/energy consumption along use stage n. Minimization of process materials in use stage
	2. Marking of hazardous components	b. Materials labeling including instructions for disposal		18. Stand-by mode energy consumption	j. Minimization of energy consumption in use stage l. Use of renewable energy resources
	3. Surface area of PCB	h. Function integration i. Standardization of components		19. Operational mode energy consumption	j. Minimization of energy consumption in use stage l. Use of renewable energy resources
	4. Number of components on PCB	h. Function integration p. Reduction of the number of materials/parts		20. Charger energy efficiency	j. Minimization of energy consumption in use stage l. Use of renewable energy resources
	5. Surface area of LCD	o. Reduction of material input	Disposal	21. Recycled material content	t. Use of recycled materials
	6. Ratio of weight/length (cable wiring)	o. Reduction of material input r. Use of lower energy content materials		22. Recyclable material content	d. Inclusion of disposal instructions for users g. Environmentally friendly surface design r. Use of lower energy content materials u. Use of recyclable materials
	7. Weight of packaging material	o. Reduction of material input r. Use of lower energy content materials x. Optimization of the weight/volume of packaging material		23. Reusable part	d. Inclusion of disposal instructions for users f. Easy upgradability g. Environmentally friendly surface design i. Standardization of components q. Reuse of refurbished parts and components u. Use of renewable materials
	8. Weight of a product	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials		24. Number of tools for disassembly	c. Easy disassembly e. Easy maintenance and repair h. Function integration
	9. Number and weight of accessory parts	c. Easy disassembly i. Standardization of components o. Reduction of material input		25. Disassembly time	c. Easy disassembly d. Inclusion of disposal instructions for users e. Easy maintenance and repair
	10. Number of kinds of material	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials		26. Number of types for joints	c. Easy disassembly e. Easy maintenance and repair h. Function integration
	11. Number of parts	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials		27. Number of joints	c. Easy disassembly e. Easy maintenance and repair o. Reduction of material input
	12. Weight and number of users manual	o. Reduction of material input r. Use of lower energy content materials x. Optimization of the weight/volume of packaging material		28. Number of parts	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials
	13. Ratio of packaging weight/product weight	i. Use of reusable packaging o. Reduction of material input x. Optimization of the weight/volume of packaging material		29. Marking of materials	b. Materials labeling including instructions for disposal c. Easy disassembly
	14. Volume of packaging box	o. Reduction of material input x. Optimization of the weight/volume of packaging material y. Use of reusable packaging material		30. Number of kinds (variety) of material	o. Reduction of material input p. Reduction of the number of materials/parts
	15. Weight of total product including packaging	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials x. Optimization of the weight/volume of packaging material		31. Warranty period	f. Easy upgradability i. Standardization of components
	16. Volume of total product (including packaging)	o. Reduction of material input x. Optimization of the weight/volume of packaging material y. Use of reusable packaging material			
Distribution					

3 Case Study

The applicability of the proposed method was evaluated using mobile phones. Five mobile phone models (all of which possess the same functions) were selected for the case study. Three products were made in Korea, and two were made in Europe. We selected mobile phones for several reasons. An enormous number of mobile phones are used in the market. While the technical life of a mobile phone is long, its use stage is short, due to rapid technological innovation. As a result, many mobile phones are discarded prematurely.

A phone produced by company XX was chosen as a reference product, and phones produced by other companies were selected as competitive products. The reference and competitive products had the highest market share in their companies. Two mobile phones produced by European companies (and sold in Europe) were also considered as competitive products. The reason for selecting these phones was because they could offer good opportunities to compare products in Korea with those in Europe. European companies have been integrating the environmental aspects of their products into the product design and development stages (Nokia 2002, Quella 2001).

3.1 Life cycle thinking for mobile phones

In order to identify the key life cycle stage of mobile phones, we assessed the LCA results for the reference product based on information from the literature. According to the MOCIE (2002) report, the weighted environmental impacts of the raw material acquisition stage were 58.7% of the total environmental impact of a mobile phone, followed by the use stage (37.5%), manufacturing stage (2.4%), disposal stage (1.1%), and distribution stage (0.3%). Similar results were obtained when other literature (Pfahl 2001, Vallés et al. 2001)

was used. The system boundaries for LCA of mobile phones in three references were the entire life cycle of a product from raw material acquisition to disposal. Thus, we identified the raw material acquisition stage as the key life cycle stage of mobile phones.

3.2 Environmental benchmarking for mobile phones

As the key life cycle stage identified in module A was the raw material acquisition stage, environmental benchmarking was carried out for 10 parameters belonging to this stage. The hazardous material content parameter was excluded due to measurement difficulty. Overall environmental benchmarking results for the 10 parameters are shown in Table 7. In the case of surface area of the PCB parameter, the area of PCB was only considered because the number of layers in PCB of the reference product and competitors are the same. But, the number of layers is as important a parameter as the surface area when expressing the environmental load. Therefore, a combination between area and number of layers expressed as 'area * layers', would be a better choice rather than just area. This is particularly reasonable when the number of layers of the reference product and competitors are different (Andræ et al. 2004).

To obtain the values in Table 7, several sub-parameters of each benchmarking parameter had to be measured. Benchmarking results for the *weight of packaging materials* parameter are presented as an example in Table 8. This parameter was divided into four sub-parameters: packaging box, inner box, user's manual, and others. The values of the sub-parameters were measured by disassembling the reference product and the competitors' products. Based on the benchmarking results, the environmental improvement targets were determined, using the difference between the

Table 7: Benchmarking results for the raw material acquisition stage for mobile phones

BP (Unit)	Mobile phone	Reference product	Competitor 1	Competitor 2	Competitor 3	Competitor 4
2. Marking of hazardous components		no	no	no	no	no
3. Surface area of PCB (cm ²)		40.1	32.4	30.4	30.6	32.5
4. Number of components on PCB (EA)		259	394	319	201	244
5. Surface area of LCD (cm ²)		14.0	10.8	10.5	6.8	10.4
6. Ratio of weight/length of cable (g/cm)		0.35	0.14	0.27	0.14	0.14
7. Weight of packaging material (g)		271.1	252.4	350.6	213.2	168.0
8. Weight of a product (g)		67.0	50.7	53.4	60.0	62.7
9. Number and weight of accessory parts (g)		246.5	315.8	217.4	254.5	143.4
10. Number of kinds of material (EA)		18	16	16	10	11
11. Number of parts (EA)		291	429	351	249	276

*BP: Benchmarking Parameter

Table 8: Benchmarking results for weight of packaging materials parameter

Item	Mobile phone	Reference product	Competitor 1	Competitor 2	Competitor 3	Competitor 4
Packaging box		88.8	96.3	153.8	63.7	62.7
Inner box		31.5	54.6	54.5	27.8	19.7
User's manual		144.2	94.1	126.4	90.5	68.4
Others		6.6	7.4	15.9	31.2	17.2
Total weight		271.1	252.4	350.6	213.2	168.0
Best product						V
Improvement target			38% reduction of packaging material			

Table 9: Best product and target specification for each benchmarking parameter

Benchmarking Parameter	Mobile phone	Reference product	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Improvement target (%)
2. Marking of hazardous components		–	–	–	–	–	*
3. Surface area of PCB				V			24
4. Number of components on PCB					V		22
5. Surface area of LCD					V		51
6. Ratio of weight/length of cable			V		V	V	60
7. Weight of packaging material						V	38
8. Weight of a product			V				24
9. Number and weight of accessory parts						V	42
10. Number of kinds of material					V		44
11. Number of parts					V		14
Total number of mark		0	2	1	5	3	

* Mark the components which contain hazardous materials such as Pb, Cd, Hg, Cr⁶⁺, PBB (Poly Brominated Biphenyls), and PBDE (PolyBrominated Diphenyls Ether)

benchmarking results for the reference product and those for the superior competitors' products. In the case of the *weight of packaging materials* parameter, the target product was competitor 4, and the improvement target was 38% [= (271.1–168.0)/271.1*100]. The same principles were applied in measuring the parameter values and in determining the improvement targets for each parameter.

Table 9 presents the best product and target specifications for each benchmarking parameter. As shown in Table 9, competitor 3 yielded the best results in five benchmarking parameters, and the reference product received many environmental improvement points. The environmental improvement targets for 9 parameters were set, ranging from 14% to 60%. The improvement target of the *marking of hazardous components* parameter is to mark the components that contain hazardous materials such as Pb, Cd, Hg, Cr⁶⁺, PBB

(Poly Brominated Biphenyls), and PBDE (PolyBrominated Diphenyls Ether) (CEC 2002b).

3.3 Environmental design information for mobile phones

The relationship between benchmarking parameters and ecodesign strategies was identified in the environmental design information module (see section 2.5). The raw material acquisition stage was identified as the key life cycle stage of mobile phones, and environmental benchmarking was carried out to identify the key environmental aspects of the product. Thus, the target specifications for the environmental benchmarking parameters and corresponding ecodesign strategies were used in determining the environmental design information for mobile phones. This information, which is presented in Table 10, was used as input to the generation of the ecodesign ideas.

Table 10: Identified environmental design information for mobile phones

Benchmarking parameter	Improvement target (%)	Ecodesign strategy
2. Marking of hazardous components	*	b. Materials labeling including instructions for disposal
3. Surface area of PCB	24	h. Function integration i. Standardization of components
4. Number of components on PCB	22	h. Function integration p. Reduction of the number of materials/parts
5. Surface area of LCD	51	o. Reduction of material input
6. Ratio of weight/length of cable	60	o. Reduction of material input r. Use of lower energy content materials
7. Weight of packaging material	38	o. Reduction of material input r. Use of lower energy content materials x. Optimization of the weight/volume of packaging material
8. Weight of a product	24	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials
9. Number and weight of accessory parts	42	c. Easy disassembly i. Standardization of components o. Reduction of material input
10. Number of kinds of material	44	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials
11. Number of parts	14	o. Reduction of material input p. Reduction of the number of materials/parts r. Use of lower energy content materials

* Indicate components containing hazardous chemicals

As Table 10 shows, the printed circuit board (PCB) was identified as one of the key environmental aspects of mobile phones. To improve the environmental aspects of PCB, its surface area must be reduced from 40.1 cm² to 30.4 cm² (24%), and its number of components must be reduced from 259 to 201 (22%). The environmental improvement ideas for PCB can be obtained by considering corresponding ecodesign strategies such as *function integration*, *standardization of components*, and *reduction of the number of materials/parts*. The same principles are applied when interpreting Table 10. A cross-functional team can use this kind of information when generating the ecodesign ideas.

4 Results and Discussion

The proposed method was compared with the LCA method and the UNEP/promising approaches, which are representative of the top-down and bottom-up approaches, respectively. The results of these comparisons are shown in Table 11.

To obtain benchmarking results through the proposed method, it is necessary to disassemble a reference product and competitors' products. Thus, this method is more time-consuming than the UNEP/promising approach. The proposed method, however, is more beneficial than the LCA method from the viewpoint of cost and time. Two or three weeks represent an acceptable time investment in identifying the environmental aspects of a product for the design and development. The proposed method proved superior in design applicability, not only because benchmarking results are expressed in designer's language, but also because ecodesign strategies give designers valuable background information. In terms of the objectivity of the results, the user can obtain good environmental analysis information by employing the proposed method. It is true that LCA can yield more detailed information than the proposed method. However, LCA is impractical for use in ecodesign, not only because it requires a significant investment in time and money, but also because designers find the results of an LCA analysis difficult to understand.

Designers can use ecodesign strategies or key issues such as components, processes, life cycle, and impact categories as the environmental design information in the UNEP/promising approach and LCA, respectively. In other words, LCA gives the bottom-up environmental information to designers, while the UNEP/promising approach yields the top-down information. In the proposed method, both the top-down and bottom-up information – target specifications of envi-

ronmentally significant benchmarking parameters and corresponding ecodesign strategies – are presented as the environmental design information and used by designers in generating the ecodesign ideas. Based on the results of this comparison, the proposed method was judged an advanced method in facilitating the generation of the ecodesign ideas. The method aids the generation of the ecodesign ideas by identifying what to improve, how much to improve, and how to improve. Environmentally significant benchmarking parameters correspond to *what to improve*, target specifications on *how much to improve*, and corresponding ecodesign strategies on *how to improve*.

When one identifies the environmental aspects of a product with the LCA or UNEP/promising approach, each life cycle stage is granted the same degree of importance. In the proposed method, a key life cycle stage is identified through consideration of the entire product life cycle in the first module (life cycle thinking for a product). The identified key life cycle stage is then subjected to intensive analysis. In this way, manufacturers can exhaustively analyze a key life cycle stage without considering stages with fewer environmental impacts. The advantages of this method are that it permits reduction in time and cost while maximizing the effects of environmental improvements. It should be noted that, in a detailed life cycle assessment of a product, one does not need to identify the key life cycle stage. In this case, it is adequate to use simple LCA-based methods such as Ecoscan, Eco-indicator 99 or the literature.

5 Summary and Conclusions

An environmental assessment method for consumer electronics was proposed and applied to mobile phones. The proposed method consists of five modules: life cycle thinking for a product, environmental benchmarking, checklist method, ecodesign strategies, and environmental design information. The applicability of the proposed method to an actual product was evaluated using mobile phones. The key life cycle stage of mobile phones identified was the raw material acquisition stage, and environmental benchmarking was carried out for 10 parameters belonging to this stage. The environmental improvement targets for the 10 parameters were set (ranging from 14% to 60%), and these target specifications were linked to the corresponding environmental strategies.

When the proposed method was compared with the LCA and UNEP/promising approaches, it was judged an advanced method in facilitating the generation of the ecodesign ideas.

Table 11: Comparison of the proposed method with the existing methods

Item \ Method	Proposed method	LCA	UNEP/promising approach
Approach	Top-down and bottom-up	Bottom-up	Top-down
Cost	Little	Much	Very little
Time	2-3 week	At least 2-3 month	Several days
Design applicability	Very good	Moderate	Moderate
Objectivity of results	Good	Very good	Moderate
Environmental design information	Target specifications of important benchmarking parameters and corresponding ecodesign strategies	Key issues (life cycle, components, impact categories, etc)	Ecodesign strategies
Scope	Mainly focus on key life cycle stage	Generally whole life cycle	Whole life cycle

The proposed method helps designers to generate the ecodesign ideas by identifying what to improve, how much to improve, and how to improve. Environmentally significant benchmarking parameters correspond to what to improve, target specifications on how much to improve, and ecodesign strategies on how to improve. It was found that the use of the proposed method minimizes the time and money expenditure by confining the identification of environmentally weak points within the key life cycle stage. The proposed method is judged to be a useful ecodesign approach for electronics companies that wish to identify the environmental aspects of their products and integrate them into the product design and development process.

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